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Introduction

Waste disposal is a responsibility of management and its importance is being recognized by industry. The use of streams as sewers is being restricted since a high percentage of water for human consumption, for recreation, and for industrial purposes is taken from surface waters. The dairy industry and other food industries are large users of water and must do their share in the elimination of pollution. Even under very carefully controlled housekeeping, about 1% of the milk handled or its equivalent is lost. Thus, a small plant handling 10,000 lb. of milk daily has a loss of about 100 lb. of fluid milk while a large processing plant receiving 500,000 lb. of milk may lose the equivalent of 2.5 tons daily (16).

The wastes discharged from a dairy consist of lost milk dispersed in cleaning water. Their strength and volume depend upon the housekeeping practiced and the type of plant handling or processing milk and milk products. Dairy plants are classified as receiving stations, bottling plants, cheese factories, creameries, condenseries, dry milk plants, or ice cream plants (1). Thus the wastes from a milk receiving station may have 6 lb. of B.O.D. per 10,000 lb. of milk handled, those from a bottling plant, 8 lb. of B.O.D., while those from a cottage cheese plant may have about 16 lb. of B.O.D., and so on depending on the many types of operations. These wastes are considerably stronger than an equal volume of municipal wastes with a B.O.D. of 150 p.p.m. For the purpose of our research,

1/ A Laboratory of the Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

We assumed a wastage of 1% and used a synthetic waste containing about 800 p.p.m. B.O.D. although, as we later found, wastes of twice this strength are not uncommon.

Studies were initiated on the treatment of dairy waste at the Eastern Utilization Research and Development Division in 1948 at the advice of the Dairy Industry Advisory Committee, which considered waste disposal one of the most critical problems of the industry. The high oxygen demand of the waste led us to study its disposal by aerobic treatment.

If we assume that the 100 lb. of milk wasted in handling 10,000 lb. is diluted by sufficient water to give a solids concentration of 1000 p.p.m., the solids content of the waste is only 0.1% and we have water 99.9% pure. This dilute material is not toxic but serves as excellent food for bacteria and causes disagreeable conditions when improperly handled. The harmful effects are caused by the lack of oxygen necessary to supply the demands of the bacteria in the waste. For example, the 100 lb. of wasted milk contains 13 lb. of solids that require almost 13 lb. of oxygen for stabilization. This amount of oxygen is found in 200,000 gal. of water (8 p.p.m. O_2 is soluble at 80°F). The limited oxygen supply is removed from solution by the microorganisms living on the waste, thus leaving none for fish or plant life unless oxygen is replaced by aeration. Natural waterways have difficulty replenishing the oxygen rapidly enough to maintain aerobic conditions with such concentrated wastes. Our pollution control agencies are justly concerned about this situation and are demanding that processors take some action to correct it.

Laboratory Studies

Details of our laboratory studies on dairy waste will not be discussed as they are available in various summaries (11,13). I shall mention only obvious phases that have led to industrial installations of the rapid aeration treatment.

If we consider the aerobic treatment of dairy waste as a rapid fermentation of a dilute solution, the need of quick tests to follow the rapid changes becomes pparent. A rapid method for the determination of organic matter originally de- ised by Dr. E. F. Eldridge was later described and used by us on many products 10,15). This chemical oxygen demand (or C.O.D.) method is a most important ool in our studies and we understand that it is now in extensive use by many anitary engineers. The B.O.D. of a waste may be readily approximated from the .O.D. if the type of material is known. For example, the B.O.D. of skim milk s about 67% of its C.O.D., that of lactose 83%, of casein 54%, of whey 86% and f aerated sludge 49% (14). Other factors may be established as needed. The dry eight of cell solids is approximated by taking 0.8 of the C.O.D.

Waste fed and aerated continuously in laboratory equipment caused 50% of ie organic matter to be converted to CO_2, providing energy for the remaining xygen-demanding material to form cell substance (4). The change may be expressed: ilk solids (organic matter) plus oxygen in the presence of bacteria produces ore bacteria plus carbon dioxide plus water. Respiration studies showed oxygen equirement to be high for the first six hours when a one-dose addition of 1000 p.m. skim milk was made to 500 p.p.m. sludge. The quantities of lactose and sein found in the waste were readily oxidized and required the same amount of ygen (2). The ratio of CO_2 evolved to the O_2 utilized, confirmed the idea at the waste was assimilated or oxidized. All nutrients were removed from lution yet complete oxidation did not occur since only 37.5% of the calculated ounts of oxygen needed for complete combustion were used.

Equations and Data

Complete oxidation of lactose proceeds according to the classical equation thus:

$$C_{12}H_{22}O_{11} \cdot H_2O \; + \; 12\,O_2 \longrightarrow 12\,CO_2 \; + \; 12\,H_2O$$

Since chemical analysis of the sludge cells (5) gave the empirical formula of $C_5H_7NO_2$, cell formation from lactose, using (CH_2O) as the sugar particle, may be expressed:

$$5\ (CH_2O) + NH_3 \longrightarrow C_5H_7NO_2 + 3\ H_2O$$

But our Warburg studies showed that while 5 carbon atoms were used for cell formation, 3 carbons or 37.5% of the total oxygen demand were oxidized as shown in the following assimilation for lactose:

$$3\ O_2 + 8\ (CH_2O) + NH_3 \longrightarrow C_5H_7NO_2 + 3\ CO_2 + 6\ H_2O$$

Equations for assimilation of casein were derived in a like manner:

$$3\ O_2 + C_8H_{12}N_2O_3 \longrightarrow C_5H_7NO_2 + NH_3 + 3\ CO_2 + H_2O$$

Fortuitously, the 240 units of sugar of the assimilation equation for lactose and the 184 units for casein is about the proportion of these ingredients found in skim milk. Hence, we can add the two equations to show what happens when skim milk is oxidized by microorganisms, the ammonia liberated from the casein is used for lactose assimilation, and the reaction remains neutral. The yield calculates to 58%, slightly higher than we found in our tests.

$$3\ O_2 + 8\ (CH_2O) + NH_3 \longrightarrow C_5H_7NO_2 + 3\ CO_2 + 6\ H_2O$$

$$3\ O_2 + C_8H_{12}N_2O_3 \longrightarrow C_5H_7NO_2 + 3\ CO_2 + H_2O + NH_3$$

$$8\ (CH_2O) + C_8H_{12}N_2O_3 + 6\ O_2 \longrightarrow 2\ C_5H_7NO_2 + 6\ CO_2 + 7\ H_2O$$

When assimilation is complete the rate of oxygen utilization dropped to that of unfed cells which undergo endogenous respiration. The following represent this step showing that 113 units of cells (minus ash) require 160 units of oxygen.

$$5\ O_2 + C_5H_7NO_2 \longrightarrow 5\ CO_2 + NH_3 + 2\ H_2O$$

Figure 1 shows the rapid rate of oxygen demand during assimilation, followed by the low rate of unfed cells when 1000 p.p.m. milk solids are added to 500 p.p.m. cells in one feeding. This low rate may represent 0.5 to 1.0%

At this juncture in our studies the laboratory results were summarized.

Oxygen required to burn 1 lb. skim milk solids	1.21 lb.
Oxygen required for assimilation (37.5%)	0.45 lb.
Time required for assimilation varies with cell concentration.	
With 500 p.p.m. cells	6 hr.
With 1000 p.p.m. cells	3 hr.
Oxygen used per hour depends on cell concentration.	
With 500 p.p.m. cells	0.075 lb.
With 1000 p.p.m. cells	0.150 lb.
New cells or sludge produced	0.52 lb.
Oxygen for complete burn up of new cells	0.75 lb.
Oxygen needed during the first 24 hours varies.	
If 1% oxidation per hour, then 20% per day, or	0.15 lb.
If 0.5% per hour, then 10% per day	0.075 lb.
Respiration requirements of seed cells.	
Oxygen to burn 1 lb. organic matter	1.46 lb.
Oxygen needed to burn 20% per day	0.29 lb.
Oxygen needed to burn 10% per day	0.15 lb.

Removal of the solubles from solution is more rapid than oxidation of he solubles (12). This property of removal may be of value in the rapid urification and separation of wastes to produce the clear liquor. Such purifi-ation may be followed by subsequent oxidation of the concentrated material, isposal by other means or possible utilization (3).

Pilot Plant Investigations

The information obtained from laboratory studies required pilot plant erification by sanitary engineers for its acceptance by the dairy industry.

A contract was made with Pennsylvania State University to carry out 0,000-gallon pilot-plant studies on the waste from the college creamery. These tudies were in charge of Professor R. R. Kountz who showed that the amounts of oxygen needed by dairy waste required aeration devices not ordinarily used for weaker wastes. For example, tests showed that when a perforated pipe was used for aeration only 1% of the oxygen in the air was dissolved and available for oxidation. Efficiencies of 2-5% were obtained with porous plates while a jet aerator permitted as much as 25% oxygen transfer. In the latter type of aerator the waste solution is forced through a Venturi type tube and air is sucked in from the atmosphere. This jet or aspirator device satisfied the high rate of oxygen required by the rapid aeration treatment. If air is forced through the air inlet under 6 lb. pressure as much as 40% of the oxygen in the air is transferred to the solution (9). Turbine type equipment is also available that permits high oxygen transfer efficiency.

A simple fill-and-draw system was developed that gave consistently high rates of B.O.D. removal with no apparent accumulation of sludge. Aeration was regulated so as to assure proper aeration when waste entered the tank. The sludge was used continually for seed. Much to the surprise of the project engineers, treatment was readily accomplished provided the conditions established in the laboratory study were satisfied. Odor was absent, removal of solubles was rapid, and sludge waste could be minimized by proper aeration over week-ends, and the process can be practically automatic.

The conditions for establishing aeration treatment of waste have been discussed (8). Design data for some typical units are in preparation. Figure 2 shows a schematic drawing of a fill-and-draw dairy waste treatment unit.

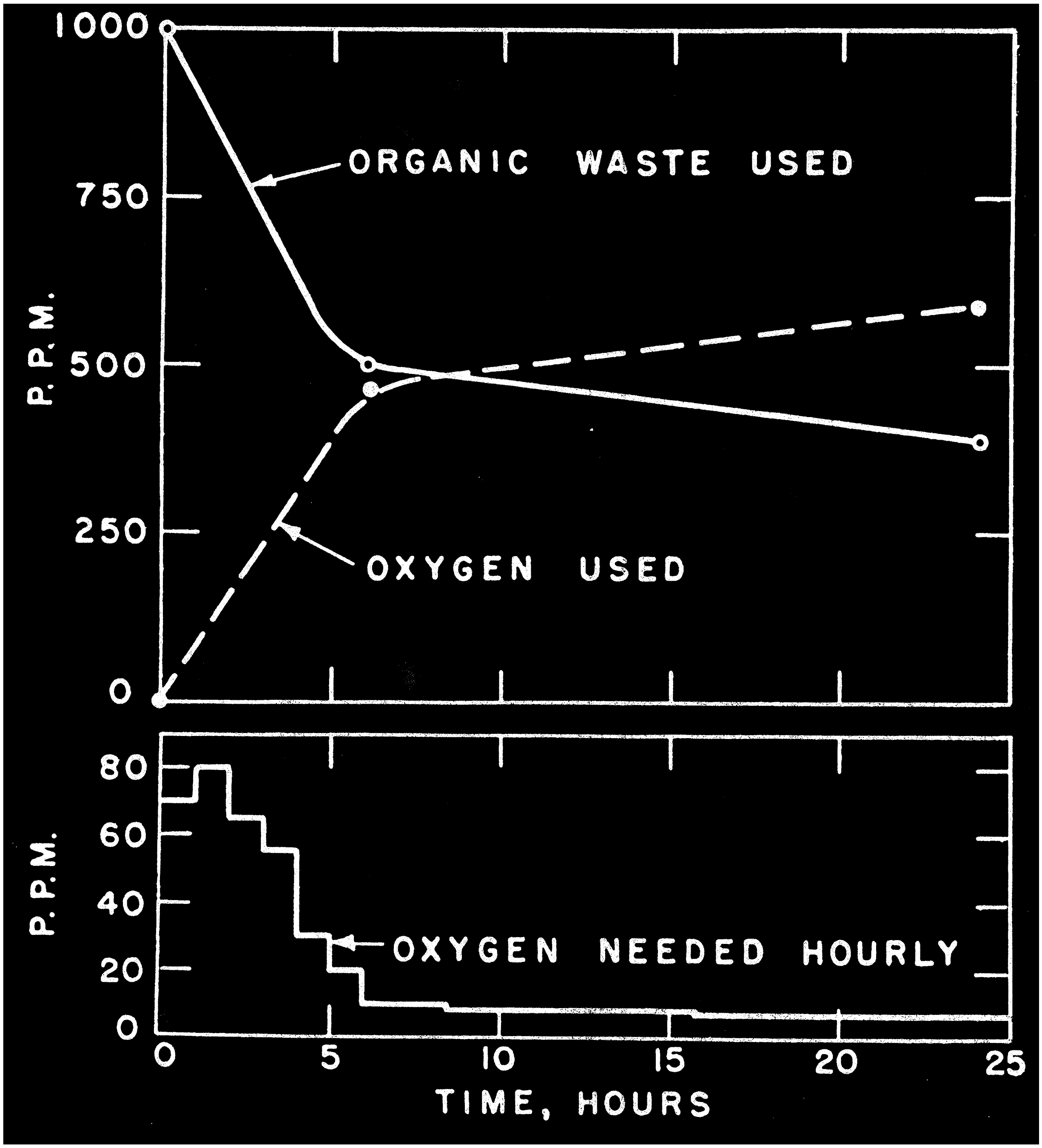
Industrial Installations

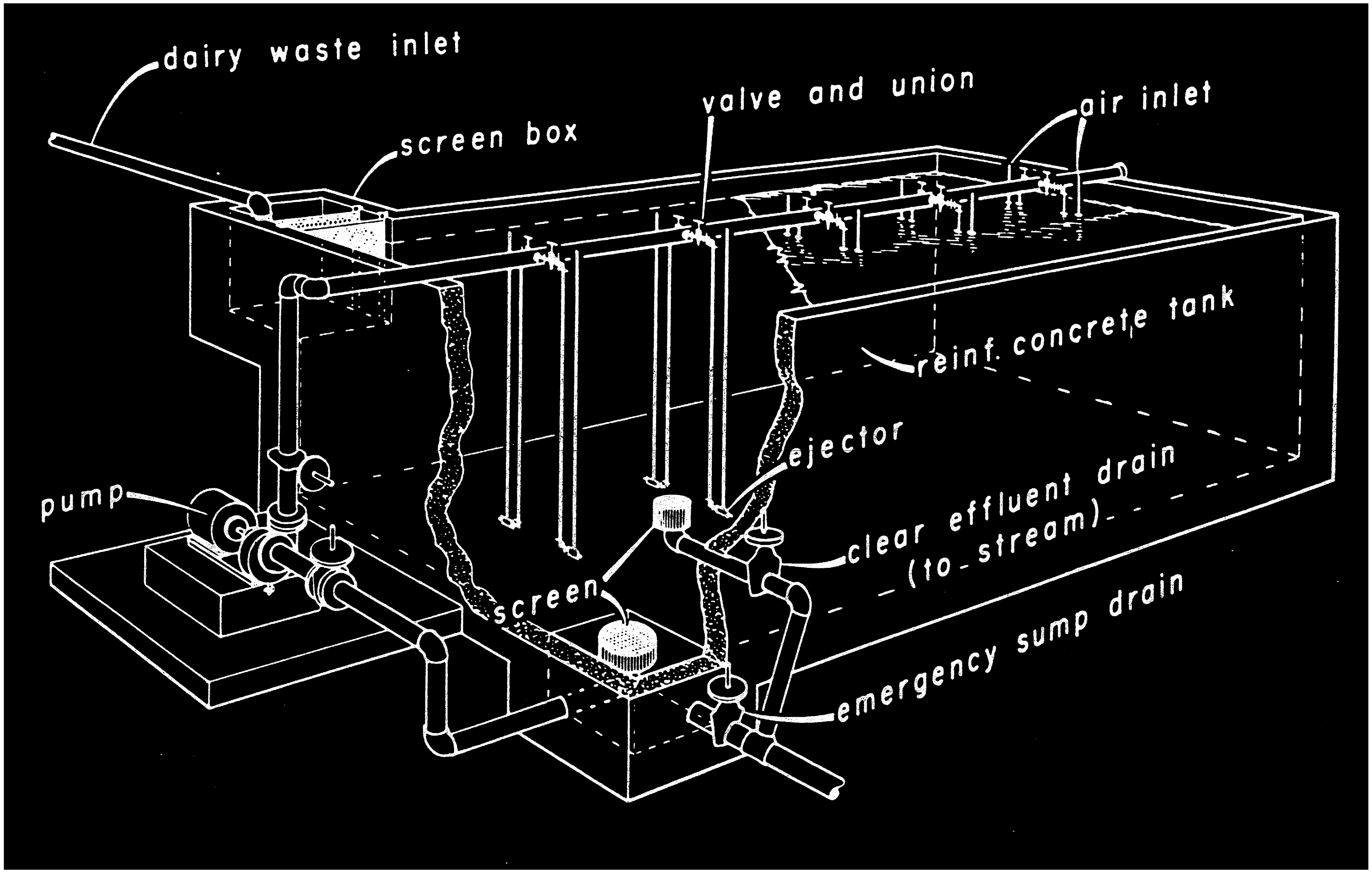
Even before the pilot plant studies were completed the opportunity presented itself to try the fill-and-draw treatment at a commercial dairy (6,7). The waste volume during 8 hours operation was 25,000 gal. and the B.O.D. was 1660 p.p.m. About 95% purification was readily obtained. The aeration tank e is 34,000 gal. and an effluent pipe is located at the 9,000-gal. level which permits draining of 25,000 gal. of clear liquor. The solids found in the waste averaged 300 lb. daily. This amount of solids produces 150 lb. of cells that are used to replace those cells lost by endogenous respiration. Since 150 lb. represents one-fifth of 750 lb., the cell solids weight carried in the aerator is 750 lb. By keeping the proper balance it is claimed that there is little or no sludge accumulation.

Calculation for total oxygen requirements are based on the oxygen required for endogenous respiration plus the amount needed for assimilation of the waste milk. Thus for 24 hours, 9.4 lb. of dissolved oxygen is needed per hour to oxidize the 150 lb. of cell substance per day. During the 8 hours when waste is added the 37.5 lb. solids per hour will require 17 lb. oxygen per hour. Hence, during the 8-hour run, a total 26.4 lb. of dissolved oxygen per hour must be supplied. Aeration is continued for a short while, the sludge is allowed to settle for an hour or more, and the supernatant is drained. Aeration of the concentrated sludge is then continued at 9.4 lb. oxygen per hour until the following morning when waste is added again and aeration is stepped up.

A jet aerator of a specific size has been found most satisfactory (9). When the waste is recirculated at 60 gal. per min., this jet dissolves 1.6 lb. of oxygen per hour. Thus although 17 jets would satisfy the oxygen, the unit has 24 to allow for excessive overloading. The waste disposal unit is practically automatic in operation and has now been in operation for over two years.

Many other plants have been put into operation and are working satisfactorily. One of the smallest treats only 5,000 gal. waste from a bottling plant surrounded by many dwellings whose occupants are well pleased with the new installation. A large continuous flow unit has been treating almost 150,000 gallons of waste daily from a processing plant. Again, there appears to be no problem of sludge disposal. It is our understanding that about 60 treatment units based upon these principles are presently in operation.


1000
750
500
250
0
P. P. M.
ORGANIC WASTE USED
OXYGEN USED
80
60
40
20
0
P. P. M.
OXYGEN NEEDED HOURLY
0
5
10
15
20
25
TIME, HOURS


dairy waste inlet
screen box
valve and union
air inlet
reinf. concrete tank
ejector
clear effluent drain
(to stream)
emergency sump drain
screen
pump

References

1. Anon. An Industrial Waste Guide to the Milk Processing Industry. U. S. Pub. Health Service Publication No. 298 (1953).

2. Hoover, S. R., Jasewicz, L., Pepinsky, J. B. and Porges, N. Assimilation of Dairy Wastes by Activated Sludge. Sewage and Ind. Wastes 23, 167-173 (19

3. Hoover, S. R., Jasewicz, L., Pepinsky, J. B. and Porges, N. Activated Sludge as a Source of Vitamin B_{12} for Animal Feeds. Sewage and Ind. Wastes 24, 38 (1952).

4. Hoover, S. R., and Porges, N. Treatment of Dairy Waste by Aeration. II. Continuous Aeration Studies. Proc. 5th Ind. Waste Conf., Purdue Univ., 137-144 (1949).

5. Hoover, S. R., and Porges N. Assimilation of Dairy Wastes by Activated Sludge. II. The Equation of Synthesis and Rate of Oxygen Utilization. Sewage and Ind. Waste 24, 306-312 (1952).

6. Kountz, R. R. Big Problem: Dairy Wastes. Striking Solution: Bio-oxidation. Food Eng. 26 (10): 89-90 (1954).

7. Kountz, R. R. Dairy Waste Treatment. J. Milk and Food Tech. 18, 243-245 (19

8. Kountz, R. R. and Porges N. Dairy Waste Treatment by Aeration. U. S. Dept. of Agriculture, Agr. Research Service, ARS-73-16; 10 p.p. (1956).

9. Kountz, R. R. and Villforth, J. C. Biological Oxidation Aerators. Proc. 9th Ind. Waste Conf., Purdue University, 53-56 (1954).

10. Pepinsky, J. B., Porges, N. and Hoover, S. R. Application of a Rapid Chemical Oxygen Demand Test for Determining Organic Pollutions. Proc. 6th Ind. Waste Conf., Purdue Univ., 367-374 (1951).

11. Porges, N. Waste Treatment by Optimal Aeration - Theory and Practice in Dairy Waste Disposal. J. Milk and Food Tech. 19, 34-38 (1956).

12. Porges, N., Jasewicz, L., and Hoover, S. R. Biochemical Oxidation of Dairy Wastes. VII. Purification, Oxidation, Synthesis and Storage. 10th Ind. Waste Conf., Purdue Univ., 135-146 (1955).

13. Porges, N., Jasewicz, L., and Hoover, S. R. Principles of Biological Oxidation. In "Biological Treatment of Sewage and Industrial Wastes," Vol. I, Aerobic Oxidation. Reinhold Publishing Corp., N. Y., p.35 (1956). Ed. by McCabe and Eckenfelder.

14. Porges, N., Jasewicz, L. and Hoover, S. R. Simple Method for Estimating Oxygen Value of Waste. Ind. Wastes 1, 95-98 (1956).

15. Porges, N., Pepinsky, J. B., Hendler, N. C. and Hoover, S. R. Biochemical Oxidation of Dairy Wastes. I. Methods of Study. Sewage and Ind. Wastes 22, 318-325 (1950).

16. Trebler, H. A. and Harding, H. G. Dairy Waste Disposal. Chem. Eng. Progress 43, 255-266 (1947).